PARALLEL SEISMIC DEPTH TESTING USING A CONE PENETROMETER

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION:

The present invention relates to apparatus and methods for testing the depth of structures such as foundations using parallel seismic testing with a cone penetrometer to house the receiving element.

DESCRIPTION OF THE PRIOR ART

Parallel Seismic (PS) testing has been employed for such uses as determining the depth of an unknown foundation when the foundation top is not accessible or when the piles are too long and slender to be tested by echo techniques. Typically a borehole is drilled into the soil adjacent to the foundation, and the borehole is cased. In the case where the receiver is a hydrophone, the cased borehole is filled with water. In the case where the receiver is a geophone, several geophone receiver components are spaced apart in the borehole.

An exposed portion of the foundation is then impacted with a hammer or the like, and compression or flexural waves travel down the foundation and are transmitted into the surrounding soil. The receiver detects the transmitted signals. The depth of the foundation is indicated by a weaker and slower signal arrival below the tip of the foundation.

Parallel seismic testing is expensive and time consuming because the borehole must be drilled and cased (or at least braced in the case of a geophone receiver).

Cone penetrometers have been used to test soil conditions. For example, Hogentogler & Co., Inc. builds a variety of commercially available cone penetrometer testers (CPTs) such as their Electronic Subtraction Cone CPTs. These units include cone tips each housing a strain gauge transducer and electronics for computing the detected strain and providing it to the user. Tips housing other transducers are also available. The CPT is mounted on a truck or track system, which includes, for example, hydraulic cylinders for driving the CPT cones into the earth.

A need remains in the art for apparatus and methods for doing parallel seismic testing in a quicker, more convenient manner.

SUMMARY

The present invention comprises three important elements:

(1) a cone penetrometer which houses a receiver;

(2) an impactor to impact the structure; and

(3) data gathering and analyzing equipment.

In the case where the receiver is a hydrophone, the hydrophone is embedded in the cone penetrometer head, and is exposed to water by a retractable sleeve or openings in the penetrometer casing prior to running tests. In the case where the receiver is a geophone or accelerometers, the retracting or perforated outer casing is not required.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 (prior art) is a side schematic view of a conventional parallel seismic

testing device.

Figure 2 (prior art) is a side schematic view of a conventional cone penetrometer.

Figure 3 is a side schematic view of a parallel seismic testing device utilizing a cone penetrometer according to the present invention.

Figures 4A-4C show preferred embodiments of the tester of Figure 3, with a variety of receivers.

Figure 5A is a plot of sample data received by the processor of the tester of Figure 3. Figures 5B and 5C illustrate two data points in the plot of Figure 5A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 (prior art) is a side schematic view of a conventional parallel seismic testing device. Foundation 101 (or some element connected to the top of the foundation, such as a pile cap) is impacted by impactor 102 (a hammer or the like). Impact hammer 102 is typically an instrumented three pound hammer producing 2000-5000 pounds of force. The instruments record (among other things) the impact time (T_0) of the impactor, so that the propagation time of waves 110 can be measured. An alternative hammer 102 might comprise a steel sledge hammer, three to eight pounds, with an accelerometer mounted next to the impact location to record the impact time.

Compressional, shear, or flexural waves 110 travel down through foundation

101 and are transmitted into the surrounding soil 112. Borehole 104 is drilled out and the drill bit removed. Borehole 104 may be cased or braced. Receiver 103 is lowered into borehole 104. Borehole 104 must be cased if receiver 103 is a hydrophone, because it is filled with water. It may be cased or otherwise braced if receiver 103 is a geophone, to prevent soil from caving in. The transmitted signals are received by receiver 103 and provided to a processor 105.

Processor 105 analyses the signals in the time domain and identifies direct arrival times of compression and shear waves, as well as their amplitudes. Generally the tests are performed every one to three feet within bore hole 104. Parallel seismic tests can be performed on concrete, wood, masonry, and steel foundations. Processor 105 is typically a computerized data collection system capable of collecting time domain waveforms at a sample rate of 20 microseconds per point or faster. Typical data traces are 1000-4000 points long, with one set of traces collected per hammer impact. Typically, a sets of tests are performed at each probe depth, with all waveforms averaged together (about two to eight waveforms) to complete one test set per probe depth. A test set would consist of an averaged impact time trace (for the signal start time) and an averaged receiver time trace.

Figure 2 (prior art) is a side schematic view of a conventional cone penetrometer tester (CPT) 201. CPT unit 204 is a van which houses and transports the CPT equipment 201, including hydraulic cylinders, mounted on a framework, driving push rods 203, which are threaded together as needed to achieve the desired depth. Push rods 203 drive the CPT cones (probe

tips) 202 into the earth 112. Instrumented cone 202 is driven into the soil 112 to be tested. The instruments might determine pore pressure, tip resistance, and sleeve resistance for bearing and skin friction value determination. CPT 201 can also be used in a seismic piezocone test, wherein the earth is impacted and compressional and shear wave energy is measured by accelerometers or geophones in the cone. A plastic casing can be installed by pushing a dummy tip to the desired location, and then leaving the internal casing in the ground as the rods 203 are withdrawn.

Figure 3 is a side schematic view of a parallel seismic testing device utilizing a cone penetrometer 301 according to the present invention. Rather than drilling a borehole and casing or bracing it, the cone penetrometer directly delivers the receiver 302 to the right depth. The cone 310 housing receiver 302 is steadily driven into the soil generally parallel to the shaft 303 to be measured. In this patent, the terms "shaft" and "foundation" are used interchangeably, and are defined to include foundations, piles, piers, caissons, footings, or other element of which the depth is to be measured. The shaft to be measured is typically formed of concrete, timber, steel, and/or masonry.

In one specific embodiment which has been implemented, a Hogentogler & Co. Electronic Subtraction Cone including a Seismic Electronic Cone Penetrometer was pushed into soil adjacent to a foundation element to be tested with a Hogentogler CPT unit mounted on Caterpillar tracks. The CPT used two double acting hydraulic cylinders coupled by a platen that pushed and pulled the push rods connected to the cone.

Periodically, as the cone 310 is being driven downward into the soil,

foundation 303 is impacted by impactor 304 (a hammer or the like). Compressional, shear, or flexural waves 110 travel down through foundation 303 and are transmitted into the surrounding soil 305. The transmitted signals are received by receiver 302 and provided to a processor 306. Processor 306 analyses the signals in the time domain and identifies direct arrival times of compression and shear waves, as well as their amplitudes.

Figure 4A shows a side schematic drawing illustrating one preferred embodiment of testing device 301, which utilizes a hydrophone 302A for receiver 302. Periodically during the time cone 310 is being driven into the soil, the pushing element pauses and allows metal cone penetrometer tip 307A to open and withdraw slightly to uncover plastic inner casing 308. Inner casing 308 is filled with water surrounding hydrophone 302A. Shaft 303 is impacted and hydrophone 302A measures the arrival time of the generated waves in the soil. Then tip 307A lowers and surrounds casing 308 and cone 310 continues its journey into the soil.

Figure 4B shows a second embodiment which utilizes a geophone 302B as the tip transducer to act as the receiver. A geophone measures movement or vibrations of the surrounding earth, for example by using the motion of a spring supported coil in the field of a permanent magnet to generate an output signal. Figure 4C illustrates a third embodiment of the present invention which includes an accelerometer 302C as a receiver. An accelerometer measures acceleration, for example by measuring the displacement of a mass connected to a spring. In the case where a geophone or an accelerometer is used, tip 307B, 307C does not generally need to be retracted while the measurement is made. The movement (pushing) of cone

310 may be paused while each measurement is made, or the measurements may be taken while the cone is moving.

In all cases, receiver 302 is detecting the arrival of waves 110 which have travelled down shaft 303 and transmitted through the soil. The amount of time between the impact and the detection of the wave is used to detect where the shaft ends, as is shown in Figure 5.

Figure 5A is a plot of sample data received by processor 306. Arrival time T increases slowly with depth until the end of foundation 303 is reached. Then arrival time increases much more quickly. As shown in Figure 5B, time T1 is measured before the end of the shaft is reached, so it is on the shallow part of the curve. As shown in Figure 5C, time T2 is measured after tip 302 has extended beyond the end of the shaft, so it is on the steep part of the the curve. Other analysis may also be performed, including amplitude and phase of signals sensed above, at and below the foundation bottom to determine its depth.

What is claimed is: